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The Economics of Cleaning Winter Wheat for Export: An Evaluation of Proposed Federal "Clean Grain" Standards

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Buyer complaints about poor quality U.S. wheat have led to proposals to enforce minimum dockage standards for exports. An economic-engineering approach is used to evaluate costs and benefits of cleaning wheat in order to meet these standards for 13 possible cleaning configurations. These results are used in an optimization framework to estimate costs and benefits of cleaning all U.S. export wheat. The estimates indicate that cleaning U.S. export winter wheat to .35% dockage would cost an average of 1¢/bu., requiring an initial capital investment of $28 million. Value of wheat lost in cleaning is a significant cost that previously has been overlooked.

Key words: dockage, grain quality, grain standards, wheat cleaning.

Introduction

Declining U.S. export market share and foreign buyer complaints about poor quality U.S. grain have raised concerns about the ability of U.S. grain to compete in overseas markets. In hopes of enhancing the reputation of the U.S. as a supplier of quality grain in world markets, numerous proposals have called for changes in the U.S. grain marketing system.

A 1989 report by the Office of Technology Assessment (OTA) suggested a range of policy options to enhance U.S. grain quality. Since variety development, grain handling, grain standards, and the market for quality characteristics all affect grain quality, the report emphasized the importance of policies that have a coordinated effect on all these areas.

However, perhaps because grain standards are the easiest of these areas to change, proposals have focused on amending grain standards to increase grain cleanliness. One difference in quality characteristics between U.S. wheat and wheat from some competitors is the higher level of nonmillable material, including dockage and foreign material (Wilson). In order to increase cleanliness of U.S. wheat, proposals have been made that would require wheat exported from the U.S. not to exceed a minimum level of cleanliness. In particular, the Grain Quality Incentives Act of 1990 (part of the 1990 U.S. House of Representatives farm legislation) directed the Administrator of the Federal Grain Inspection Service (FGIS) to establish or amend grain standards to include economically and commercially practical levels of cleanliness for several export commodities, including wheat. Further, the Act specified that these standards are to decrease the levels of objectionable material permitted in shipments of grade 3 or better.[1]

U.S. grain handlers already use segregation to improve export wheat. The cleanliness

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of export wheat exceeds average cleanliness of U.S. new crop wheat in most years (Adam and Anderson). Short of extensive changes in the production system to deliver cleaner wheat to the first handler, increasing the cleanliness of U.S. export wheat likely will require post-harvest mechanical cleaning. Cleaning is a relatively economical means of removing dockage[2] and shrunken and broken kernels. In addition, some foreign material may be removed in cleaning. Cleaning wheat reduces transportation costs and insect infestation and increases storability. Further, clean wheat may receive a premium from some buyers.

Opponents of a mandatory cleaning program for export wheat maintain that cleaning costs will be more than the benefits, and suggest that foreign buyers use quality complaints to bargain for lower prices (Hill 1988). They point out that if buyers want and are willing to pay for a lower level of dockage in wheat, the current market-based system facilitates this. However, because the market for cleaner wheat may be relatively thin, buyers specifying unique quality characteristics may incur higher prices. In addition, economies of size in cleaning imply that cleaning costs may be higher if done for a limited number of buyers (Hill 1990, p. 305). Cleanliness standards for export grain may enable firms to take advantage of these economies.

There are also strategic arguments for mandatory cleaning of U.S. wheat. Cleaner wheat may lead to enhanced reputation and increased market share for U.S. wheat. Wheat cleanliness may therefore be a means of differentiating U.S. wheat and is partially a public good since the enhanced reputation of U.S. wheat might benefit all exporters. Other public good arguments for cleaning wheat include increased worker health and safety and reduced pesticide usage.

There is evidence to support the idea that countries, as well as firms, can pursue product differentiation strategies and that reputation has an impact on the price received in international markets. Grennes, Johnson, and Thursby indicate that country of origin is one basis of differentiation in demand for wheats. Both Rackstraw and Leath argue that the U.S. could increase grain export sales by competing on nonprice factors such as quality and reputation. The Canadian government pursues a strategy of differentiation by maintaining control over variety development and release and by requiring that all export grain be cleaned (Carter, Loyns, and Ahmadi-Esfahani).

Wilson found empirical evidence that country of origin has an unexplained impact on wheat prices in international markets. After accounting for quality characteristics such as hardness and protein, there were still significant implicit values for country of origin in international wheat prices. In his view, this reflected the cumulative impact of the production/marketing system in each country as well as the institutions, policies, and trade practices.

Further, wheat cleaning may be considered a public good since the removal of nonmillable material from wheat may have safety and health implications. Grain dust represents a risk to worker safety from both a respiratory standpoint and the increased chance of dust explosions. Cleaning wheat may be an effective method of reducing the negative impacts of grain dust during loading, unloading, and handling of U.S. exported wheat. Additionally, cleaning wheat may have benefits in reducing pesticide use and pesticide residues. Insect activity in stored grain is concentrated in the "fine core" of material near the center of the bin. Cleaning grain removes this favorable insect habitat and is therefore part of an integrated pest management system of reducing pesticide use in stored grain (Noyes, Weinzierl, and Cuperus). Dockage, such as crust, chaff, and broken kernels, also absorbs fumigant vapors and other pesticides, reducing effectiveness of insect control and increasing residues (Cuperus, Criswell, and Sargent).

This article estimates costs and benefits to the grain industry of cleaning export grain to achieve cleanliness standards. If pecuniary benefits exceed costs, cleanliness standards would increase industry profits, particularly if a premium for cleaner grain could be obtained. However, if the benefits of cleaning are insufficient to cover costs of cleaning, then a market premium for cleaner wheat must be identified before cleaning wheat would be economically profitable.

Even if cleaning wheat is not profitable, policy makers could initiate a mandatory cleaning program on the basis of the public good aspects of cleaner U.S. wheat. In this case, the negative net benefit can be viewed as the net cost to the industry of a strategic move to increase reputation, enhance worker safety, and reduce pesticide usage.

The possibility of mandatory wheat cleaning for non-economic reasons raises the issue of how the net costs of cleaning might be distributed among firms, states, and regions. Although a complete treatment of this issue is beyond the scope of this research, the state-by-state estimates of net benefits from cleaning wheat provide insight into the regional impacts of a mandatory cleaning program. Similarly, the conclusions as to the most cost-effective location in the market chain to clean wheat (country, terminal, or port elevator) provide important insights into the impact on different types of firms.

A proper evaluation of proposed cleanliness standards depends on an accurate assessment of the costs and benefits of cleaning wheat. Although many elevators clean wheat containing higher than normal levels of dockage down to a normal dockage level (.6–1%), few U.S. elevators routinely clean wheat on a commercial scale to a level comparable to that of U.S. competitors. Thus, few studies have examined costs and benefits of cleaning winter wheat to lower than normal levels of dockage using the range of types and sizes of cleaning configurations available.

Fridirici et al. calculated that cleaning wheat using a Canadian-type system at export ports would cost about 13.7¢/bu., and at inland terminal elevators about 4.1¢/bu. Their estimates included labor, maintenance, and energy costs, but not value of wheat removed in cleaning. Their study did not consider potential benefits of cleaning wheat.

A case study by Kiser examined costs and benefits of cleaning at a country elevator using a rotary screener and an aspirator. The cost of reducing dockage to .5% ranged from 1.3¢/bu. for the aspirator to 1.6¢/bu. for the screen cleaner. Although the results suggested that cleaning likely would be profitable under typical conditions, value of wheat removed in cleaning was not included as a cost.

More recently, Scherping et al. used survey results and engineering cost analysis to estimate costs and benefits of cleaning spring wheat. Johnson and Wilson used these results to formulate a model of country elevator cleaning and blending decisions. Although these studies included value of wheat lost in cleaning as a cost, the results are not directly applicable to winter wheat.

Our analysis builds on these studies and others by estimating economic-engineering relationships between amount of wheat and nonwheat material removed and cleaning efficiency for a range of cleaner types appropriate for country, subterminal, and port elevators. Cleaners of various sizes and types are considered in order to assess effects of economies of size and capacity utilization on profitability of cleaning wheat. In addition, the analysis estimates the value of wheat lost in cleaning. This value is a component of cleaning cost for which little information previously has been available, and which often has been overlooked.

The next section outlines procedures for estimating net benefit of cleaning. Economic-engineering procedures are described first for representative firms operating under nearly ideal conditions, using devices appropriate for cleaning at country, subterminal, and port elevators. Since only a small amount of wheat currently is cleaned, little historical data are available to evaluate cleaning costs and benefits. The use of an economic-engineering approach allows estimation of costs and benefits for a range of operating environments and technologies which may or may not be in current use.

Procedures are described next for estimating costs and benefits of cleaning all U.S. export wheat to meet cleanliness standards. The economic-engineering analysis for representative firms is expanded to model the effects that differences among states and marketing levels have on operating environment and costs and benefits of wheat cleaning. Adjustments to the model capture differences in grain shipment patterns and markets, input costs, types of cleanliness problems, and capacity constraints. Both the representative firm and national analyses highlight differences in cleaning profitability across different operating environments and the assortment of cleaning configurations necessary to maximize net cleaning benefit.

Procedures

Representative Firm Costs and Benefits

Engineering data are used to assess the inputs required for the cleaning process. These are combined with economic parameters to determine the costs of cleaning. Similarly, economic, engineering, and entomological data are combined with economic parameters to quantify benefits of cleaning wheat.

Costs of cleaning include fixed investment and insurance, value of wheat removed in cleaning, and labor and energy costs. Benefits include any premium received for cleaner wheat, value of any grade improvement, value of cleanings sold, savings in transportation costs, reduced cost of aeration, reduced cost of insect management, and value of additional storage space gained. A summary of calculations of net benefit of cleaning wheat is as follows:

net benefit/bushel = *benefit/bushel* − *cost/bushel.*

where *benefit/bushel*

= premium for clean wheat

+ value of grade change

+ value of cleanings sold [(nonwheat material removed + wheat lost in cleaning) × cleanings price]

+ transportation savings [(nonwheat material removed + wheat lost in cleaning + wheat lost in handling) × transport rate for wheat]

+ aeration savings (reduced cost of aeration × % stored × % of year stored)

+ insect management savings (reduced cost of insect management × % stored × % of year stored)

+ storage savings (value of additional storage space gained by storing less dockage);

and *cost/bushel*

= fixed cost/bushel

= [purchase cost + installation cost) × life] ÷ $PVIFA_{ni}$[3] + insurance cost/year

+ variable cost

= labor cost [(operating labor × operating wage rate) ÷ throughput + (supervisory labor × supervisory wage rate) ÷ throughput]

+ energy cost [(kwh × electric rate) ÷ throughput]

+ value of wheat removed in cleaning {[nonwheat material (except dockage removed) + wheat lost in cleaning + wheat lost in handling] × price of wheat}.

Benefits and costs in the above summary are explained in the two following subsections.

Benefits.

(*a*) Premium for Clean Wheat: Some buyers may pay extra for cleaner wheat. Recent surveys discussed by Mercier suggest that dockage is of secondary importance in import decisions of most foreign buyers, and that any premiums offered for cleaner wheat likely would be small and offered by only a few buyers. Moreover, responses by competitors likely would dissipate most gains achieved by exporting cleaner wheat. Therefore, this analysis assumes that the market premium for clean wheat is zero.

(*b*) Value of Grade Change: Dockage is not a grade factor in current FGIS grades and standards, so removing dockage alone will not change grade. Rather, dockage is subtracted from gross weight. However, cleaning wheat usually removes small amounts of foreign material (fm) and shrunken and broken kernels (s&b), which are grade factors, in addition to dockage. Relationships estimated by Duncan and Kiser from field trials were used to model the amount of fm and s&b removed in cleaning.[4] Current grades and premium/discount schedules are used to evaluate the effects of cleaning on wheat grade.

(*c*) Value of Cleanings Sold: The price of cleanings differs markedly among locations. At one extreme, an elevator may have to pay to dispose of cleanings. At the other, the average market price of wheat cleanings in Kansas City is $80/short ton, or $4/cwt. A concern is that if more wheat were cleaned, the market for cleanings would be affected significantly. The cleaning price used in this study is based on a 1991 National Grain and Feed Association (NGFA) survey which indicated that elevators that clean receive an average of $2/cwt for cleanings (Adam and Anderson). The quantity of cleanings sold is assumed to be the amount of wheat and nonwheat material removed in cleaning. Cost of transporting cleanings is deducted from the price of cleanings, so price of cleanings is expressed as f.o.b. origin.

(*d*) Transportation Savings: Dockage is deducted from sale weight. However, since transportation charges apply to gross weight, removing dockage reduces transportation charges. Also, during the cleaning process, some fm and s&b are removed, allowing additional wheat to be shipped. Transportation savings from cleaning are equal to the transportation rate times the amount of wheat and nonwheat material removed in cleaning.[5]

(*e*) Aeration Savings: Cleaned grain takes less time to aerate than "dirty" grain, thus saving energy (Noyes). Aeration time varies with the aeration rate, and power required varies with depth of grain mass. An estimate of aeration costs based on grain depth, amount of dockage in wheat, and electricity costs is: cost of aeration ($/bu.) = $.00004871 \times \exp[.02639 \times \text{grain depth (ft.)}] \times (14.3 \times \%\ \text{dockage} + 115) \times \text{electric rate (\$/kwh)}$. It is assumed that 50% of wheat cleaned at country and subterminal elevators is stored for six months, and that no storage occurs at port elevators.

(*f*) Insect Management Savings: An entomological analysis conducted as part of this research concluded that the combined loss due to not cleaning is approximately .2¢/bu., assuming, as above, that 50% of cleaned grain is stored for half a year.[6] This estimate may slightly underestimate savings since weight loss due to insect damage was assumed only to occur in the "fine core" area of a grain storage structure, where insect populations are highest.

(*g*) Storage Savings: Removing dockage and other nonwheat material increases amount of space available in which to store wheat. The value of this additional storage space is multiplied by the percentage of the crop stored and the amount of time it is stored. If existing storage capacity is not being used, the value of additional storage space may be small in the short run. In the long run, however, the value of additional storage space will approach the true cost of maintaining storage facilities. The value of storage space is assumed to be 2.5¢/bu. per month for country and subterminal elevators.

(*h*) Insurance Savings: Insurance savings may result if cleaning reduces the risk to the firm of explosion or other damage or injury to its employees. A small survey of insurance companies found that none offered a reduction in insurance rates for grain storage facilities for cleaning grain before storage. No insurance benefit is assumed.

Table 1. Characteristics of 13 Selected Cleaning Machines

Machine	Type	Purchase Cost ($)	Rated Capacity (bu./hr.)	Optimal Capacity (bu./hr.)	Horse-power Re-quired	%W*	Capacity Parameters**		
							a	*b*	*c*
1	Disc Cylinder	24,185	500	398	7.50	14.0	40.7	10.60	74.3
2	Disc Cylinder	39,310	1,000	795	13.75	14.0	40.7	10.60	74.3
3	Rotary Screen	69,342	2,000	1,374	10.00	9.0	32.2	7.70	64.0
4	Rotary Screen	76,265	5,000	3,436	10.00	9.0	32.2	7.70	64.0
5	Rotary Screen	82,573	10,000	4,808	10.00	9.0	30.8	7.30	43.5
6	Screen	47,000	5,000	4,230	7.50	9.0	37.2	12.25	82.0
7	Screen	165,000	22,000	19,400	15.00	9.0	31.2	11.00	86.6
8	Combination	30,695	2,500	1,719	15.00	11.2	63.0	4.94	50.9
9	Combination	47,243	3,500	2,406	20.00	11.2	63.0	4.94	50.9
10	Combination	67,553	7,000	4,813	40.00	11.2	63.0	4.94	50.9
11	Portable Aspirator	18,000	2,500	2,285	15.00	36.4	31.3	2.82	51.73
12	Aspirator	35,000	7,000	6,399	50.00	36.4	31.3	2.82	51.73
13	Aspirator	45,000	12,000	10,970	65.00	36.4	31.3	2.82	51.73

* Percent wheat in cleanings by weight, where

$$\text{lbs. wheat removed} = \text{lbs. total material removed} \times \frac{\% W}{100 - \% W}.$$

** Capacity parameters are used to calculate % rated capacity, where % rated capacity = a × final dockage − b × initial dockage + c.

Costs.

(*a*) Equipment Configurations: Thirteen cleaning configurations, ranging in rated capacity from 400 bu./hr. to 22,000 bu./hr., are analyzed (table 1). Since some kinds of dockage are more efficiently removed with one type of machine than another, the set of configurations included several kinds of cleaning technology.[7]

Depending on the configuration, a system may be adjusted to clean wheat to various levels of dockage. Typically, the more material to be removed in cleaning, the lower the cleaning capacity and the more wheat removed.

For each cleaning machine, engineering estimates give a relationship between initial and final levels of dockage and the capacity at which the machine can be operated. A cleaner operates closer to its rated capacity with lower initial dockage, or if wheat is cleaned less thoroughly (higher final level of dockage). The relationship is expressed as:

$$\% \text{ rated capacity} = a \times \text{final dockage} - b \times \text{initial dockage} + c,$$

where a, b, and c are positive constants applying to particular cleaning machines.

For most machines, a is several times larger than b, indicating that cleaning to a low final level of dockage reduces throughput much more than does a high initial level of dockage (table 1). When throughput is reduced, labor and energy costs per bushel are higher. Also, lower throughput implies that fewer bushels are cleaned per year, resulting in higher fixed costs per bushel.

Each cleaner is assumed to be configured so that cleaning takes place in conjunction with other elevator operations, such as receiving, turning, or loading. This implies that less labor and energy are used since less extra handling is required. Also, conveying belts and other equipment used to handle wheat to be cleaned can be integrated into other parts of the elevator's operations, requiring fewer resources devoted exclusively to cleaning.

It is assumed that the elevator borrows money to purchase and install the equipment and that loan repayments are equal over the life of the equipment. Installation costs are estimated by engineers and manufacturers to be equal to the actual equipment cost.

(*b*) Variable Cost: Three components of variable cost are labor, energy, and maintenance. These costs, related to hours of use, are expressed as costs per bushel of precleaned wheat by dividing hourly labor, energy, and maintenance costs by the hourly throughput of the cleaner. The throughput used assumes that the cleaner is operated at or near the optimal speed, not necessarily the manufacturer's rated throughput. A fourth component of variable cost is the value of wheat and other material lost in cleaning and handling.

(1) Labor, Energy, and Maintenance Cost: Labor required is one hour of operating labor and .1 hour of supervisory labor per hour of machine time. The wage rate for operating labor is \$6/hr., and for supervisory labor is \$13/hr. Hourly energy use is the sum of energy required to operate the cleaner and energy required to convey wheat to the cleaner. Maintenance is assumed to require an additional .5 hours of operating labor for every 40 hours of operation.

(2) Value of Material Removed in Cleaning: A cost that has been overlooked in previous studies is value of wheat removed in cleaning. When wheat is cleaned, some good wheat passes through with the screenings and liftings during the cleaning process. This wheat typically is sold as cleanings. The amount of wheat removed in cleaning depends on the type of cleaner (table 1), as well as on the appropriateness of the settings and the amount of material removed in cleaning. In addition, some wheat is lost in handling.

Samples of screenings and liftings were collected at several cleaning locations throughout the wheat belt from different types of cleaners. The samples were screened to separate the wheat from dockage, fm and s&b. The percentage of wheat removed in cleaning (%*W*) was determined on a weight basis for each sample.

The amount of wheat removed, based on the total amount of material removed (the total weight of dockage, fm, s&b, and wheat itself), can be expressed as:

$$\text{lbs. wheat removed} = \text{lbs. total material removed} \times \frac{\%W}{100 - \%W}.$$

For example, if 1% of wheat and nonwheat material were removed from 100 lbs. of wheat using a disc separator, the amount of wheat removed from the 100 lbs. would be: 1 lb. × 14 ÷ (100 − 14) = .16 lb. It is estimated that an additional 1/10 of 1% of wheat is lost in handling. Also, since the fm and s&b removed in cleaning could otherwise be sold as wheat, the total value of material removed in cleaning is the amount of wheat removed in cleaning and handling, plus the amount of fm and s&b removed in cleaning, times the price of wheat.[8]

National Costs and Benefits of Cleaning Export Winter Wheat

The second component of the analysis of costs and benefits of cleaning wheat expands the representative firm model to consider state- and marketing-level differences in cleaning all U.S. export winter wheat. The representative firm economic-engineering estimates are adapted by imposing constraints on grain shipment patterns and markets and on types of cleaners used, and by adjusting model parameters. In particular, adjustments are made to costs of labor and transportation, price of wheat, and amount of wheat cleaned each year. In addition, the type of cleaner is restricted to those types appropriate for dockage problems in a particular area.

These adjustments are determined for each state and marketing level. Whereas the representative firm estimates assume that all cleaning configurations are operated at full capacity and that model parameters are representative of all elevators, these constraints and parameter adjustments allow for differences in operating conditions among elevators in different regions and at different marketing levels.

The optimal cleaning configuration and marketing level (location) for cleaning each state's wheat exports is selected using an iterative optimization process. In the optimization model, each state is viewed as a firm choosing the optimum cleaning configuration and location, given that all export wheat must be cleaned to a maximum level of dockage.

Thus, for each state from which elevators send wheat to export ports, the following model is solved:

$$(1) \qquad \max_{i,j} \; Net\ Benefit_{i,j} = Benefit_{i,j} - Cost_{i,j}$$

s.t. physical constraints and market parameters,

where i = cleaning configurations 1 through 13, and j = country, subterminal, or port elevator marketing level.

Each state chooses a cleaning configuration i from 13 possibilities and a marketing level j at which to install the cleaners from three possibilities. The number of cleaners installed at the chosen marketing level depends on the amount of the state's wheat to be cleaned and the capacity of the cleaning configuration chosen.

In the optimization model, each state faces market parameters and physical constraints. The main physical constraint is the dockage problems typically encountered, which restricts choice of cleaners. Market parameters include port destinations, transportation costs to those ports, labor wage rates, wheat prices, and amount of wheat handled by the state's elevators. They are based on a 1985 study of U.S. grain flows (Reed and Hill) and 1985 price data. The grain flow data were used to model grain flow patterns, including export shipments, from each wheat-producing state.

Since there often is as much variation among elevators within a state as there is from state to state, state-by-state results should be viewed as illustrative of differences among elevators facing different situations. Per bushel costs, benefits, and net cleaning benefit for each state are weighted by that state's number of bushels cleaned to get weighted U.S. averages of the state-by-state results.

The following paragraphs describe parameter adjustments to allow for differences among states and marketing levels. Then the optimization procedures for allowing each state to choose the optimal cleaning configuration and location are described.

State-by-State and Marketing Level Adjustments.

(*a*) Transportation Savings: Transportation savings for each state is percentage by weight of material removed from each bushel in cleaning, times the transportation cost per bushel. Transportation cost is the cost of transporting wheat from an elevator to an export port, plus the cost of ocean freight to the export destination.[9]

The cost of transporting wheat from a country elevator to an export port via subterminal elevator is assumed to be the difference between the port price and the state's average price received by farmers, less combined country, subterminal, and port elevator merchandising in-and-out margins of 21¢/bu.[10] Port price for each state is the yearly average port prices for Great Lakes, Atlantic, Gulf, and Pacific ports, weighted by the proportion of the state's export shipments shipped to each port. The cost of ocean freight is assumed to be $20 per metric ton, the average over recent years (Adam and Anderson).

Transportation savings are highest when wheat is cleaned at the country elevator. If wheat is cleaned at a subterminal elevator, the savings in transportation cost is reduced because the wheat is transported only a portion of the distance from the country elevator to the export port after cleaning. The reduction in savings is the transportation cost from country to subterminal elevator times the weight removed in cleaning. If wheat is cleaned at a port elevator, the savings is reduced further, with total transportation savings equal to the ocean freight rate times the percentage by weight removed in cleaning.

(*b*) Labor Cost: Wage rates used in the individual firm analysis are adjusted for each state by the percentage that each state's average wage rate from the *Survey of Current Business* (U.S. Department of Commerce) deviates from the national average.

(*c*) Wheat Prices: Wheat prices affect the value of wheat removed in cleaning; the higher the price of wheat, the higher the cost of cleaning. The price of wheat at country elevators in each state is the yearly average price received by farmers plus a country elevator merchandising margin of 7¢/bu. The price of wheat is higher at subterminal elevators than at country elevators by the cost of transportation from country to subterminal and merchandising margin at the subterminal elevator. The price is higher at port than at subterminal elevators by the cost of transportation from subterminal to port and the port elevator merchandising margin.

(*d*) Amount of Wheat Cleaned: The annual throughput of an elevator directly affects the amount of wheat cleaned. An elevator with low throughput will clean less wheat, and will have higher average fixed and average variable costs of cleaning.[11] Assuming that a cleaning configuration can be used for all classes of wheat handled by an elevator, spreading fixed cost over as large a volume as possible, the throughput for country (subterminal) elevators is the average amount of wheat (all classes) handled by country (subterminal) elevators in a state responding to the NGFA survey. If there were no survey respondents for country (subterminal) elevators in a state, a throughput equal to the average throughput for country (terminal) elevators in other states is assumed. The amount of wheat cleaned at each port is the amount of wheat exported from that port that has not been cleaned at a country or subterminal elevator.

It is not assumed that all elevators in a state install cleaning equipment. The number of equivalent cleaning configurations installed at country, subterminal, or port elevators is the amount of wheat cleaned divided by the throughput of the cleaning configuration, rounded up to the nearest integer.[12] The amount of wheat cleaned in each state is 1985 production of all classes of wheat multiplied by the percentage of the state's production shipped to export locations in 1985.

(*e*) Type of Material to Be Removed in Each State: The choice of cleaner influences both costs and benefits of cleaning wheat. The type of cleaner required to clean wheat in each state depends on the composition of the most typical dockage in each state. Common dockage problems in each state were identified by survey of crop and weed specialists in each state. Materials that are substantially larger or smaller than wheat can be easily separated from wheat with screen type cleaners or combination screen-aspirators. Materials that are substantially heavier or lighter require either an aspirator or a combination screen-aspirator. Materials nearly the same size and weight as wheat are the hardest to separate. A disc separator, which separates partly by shape, combined with a scalper and aspirator, is best at separating these materials. Only those cleaning configurations that would be appropriate for a state's common dockage problems are allowed to be selected. For some states, this may prevent elevators from using the lowest-cost configuration. Cleaning configurations at port elevators must be appropriate for all states cleaning wheat at that port.

Solution Procedures.

Using the parameter adjustments described above, costs and benefits of cleaning wheat are calculated as in the representative firm analysis, and the configuration and cleaning location with highest net benefit is selected for each state. Since cleaning cost at each marketing level depends on volume of wheat cleaned, determining the optimal cleaning configuration and cleaning location for each state requires an iterative process.

First, the amount of wheat handled by country and subterminal elevators in each state is multiplied by percentage of wheat from that state moving through export ports. This gives number of bushels cleaned annually by country or subterminal elevators. For port elevators, to begin the iteration, the amount of wheat cleaned is set equal to the amount exported through the port from all states. This starting point results in the lowest possible average cost for port elevators, since not all wheat exported through a port is necessarily cleaned at the port. Succeeding iterations reduce the amount of wheat cleaned at export ports by subtracting amounts cleaned at country and subterminal elevators.

Table 2. Parameters Used in Calculation of Net Benefit of Cleaning Wheat for Individual Firm

Parameter	Standard Value
Price of Wheat	$3/bu.
Value of Cleanings (f.o.b. local)	$2/cwt
Operating Labor Wage	$6/hr.
Supervisory Labor Wage	$13/hr.
Electric Rate	10.5¢/kwh
Interest Rate	12%/yr.
Hours of Operation	1,000 hrs./yr.
Premium for Cleaned Wheat	0¢/bu.
Transporation Rate for Wheat	75¢/bu.
Percent Shipped by Rail	50%
Percent Shipped by Truck	50%
Percent of Cleaned Wheat Stored	50%
Target Level of Dockage	.35%
Beginning Level of Dockage	.85%

Second, the costs and benefits of cleaning these amounts of grain are computed for each cleaning configuration appropriate for wheat produced in that state, for country, subterminal, and port elevators.

Third, equation (1) is optimized, selecting the cleaning configuration and cleaning location with highest net benefit from all allowable cleaning configurations and locations. The per bushel net cleaning benefit with this configuration is assumed to apply to as many country, subterminal, or port cleaning facilities as are needed to clean export wheat from that state.

The fourth step reduces the amount of wheat cleaned at port elevators to equal the amount of export wheat not cleaned at country or subterminal elevators. This raises average costs and reduces net benefit of cleaning at port elevators compared to country and subterminal elevators. In turn, as the iterations continue and equation (1) is reoptimized, amount of wheat cleaned at ports may be further reduced, again raising costs and reducing net benefit of cleaning at port elevators. The second, third, and fourth steps are repeated until there is no further change in chosen configurations and locations.

These calculations imply that average variable costs may differ across states and across country, subterminal, and port elevators (market levels) because of differences in wage rates, price of wheat, and value of cleanings. Average fixed and variable costs may differ across states and market levels because of differences in number of bushels cleaned per elevator. Benefits and both variable and fixed costs may differ with type of cleaner chosen. Benefits also may differ both across states and across marketing levels because of differences in transportation savings.

Results

Representative Firm Estimates

Initial values for parameters used in the representative firm analysis are shown in table 2. These values are best estimates for conditions facing typical elevators in the winter wheat region. Computed costs, benefits, and net benefit for each of the 13 cleaning configurations considered are presented in table 3. These calculations indicate that costs of cleaning wheat exceed benefits by .5¢/bu. to 3.9¢/bu., depending on the configuration used. From another perspective, individual firms would need to receive these amounts as premiums for clean wheat for cleaning wheat to be a breakeven proposition, holding other parameters constant.[13]

Table 3. Costs, Benefits, and Net Benefit of Cleaning Winter Wheat for 13 Selected Cleaning Machines (¢/bu.)

Machine	Fixed Cost	Wheat Loss	Labor Cost	Energy Cost	Total Cost	Cleanings Value	Transport Savings	Fumigation/ Aeration/ Storage Savings	Total Benefit	Net Benefit
1	1.6	2.3	1.9	.3	6.0	1.4	.5	.2	2.1	−3.9
2	1.3	2.3	.9	.3	4.8	1.4	.5	.2	2.1	−2.7
3	1.3	2.1	.5	.2	4.1	1.3	.5	.2	2.0	−2.1
4	.6	2.1	.2	.1	3.0	1.3	.5	.2	2.0	−1.0
5	.4	2.4	.2	.1	3.1	1.5	.5	.2	2.2	−1.0
6	.3	2.1	.2	.1	2.6	1.3	.5	.2	2.0	−.7
7	.2	2.1	.0	.1	2.4	1.3	.5	.2	2.0	−.5
8	.5	2.2	.4	.2	3.2	1.3	.5	.2	2.0	−1.2
9	.5	2.2	.3	.2	3.2	1.3	.5	.2	2.0	−1.1
10	.4	2.2	.2	.2	2.9	1.3	.5	.2	2.0	−.8
11	.2	3.5	.3	.1	4.1	1.9	.6	.2	2.7	−1.4
12	.1	3.5	.1	.1	3.9	1.9	.6	.2	2.7	−1.1
13	.1	3.5	.1	.1	3.8	1.9	.6	.2	2.7	−1.1

Note: The initial parameter values shown in table 2 are used here.

Average cleaning cost differs substantially among sizes and types of cleaners, ranging from 6¢/bu. for machine #1, a small disc separator, to 2.4¢/bu. for machine #7, a large screen cleaner. The smallest component of total cost is energy cost, and the largest component of cost is the value of wheat removed in cleaning (see fig. 1). Although value of wheat removed often has been neglected in previous studies of cleaning costs, its impor-

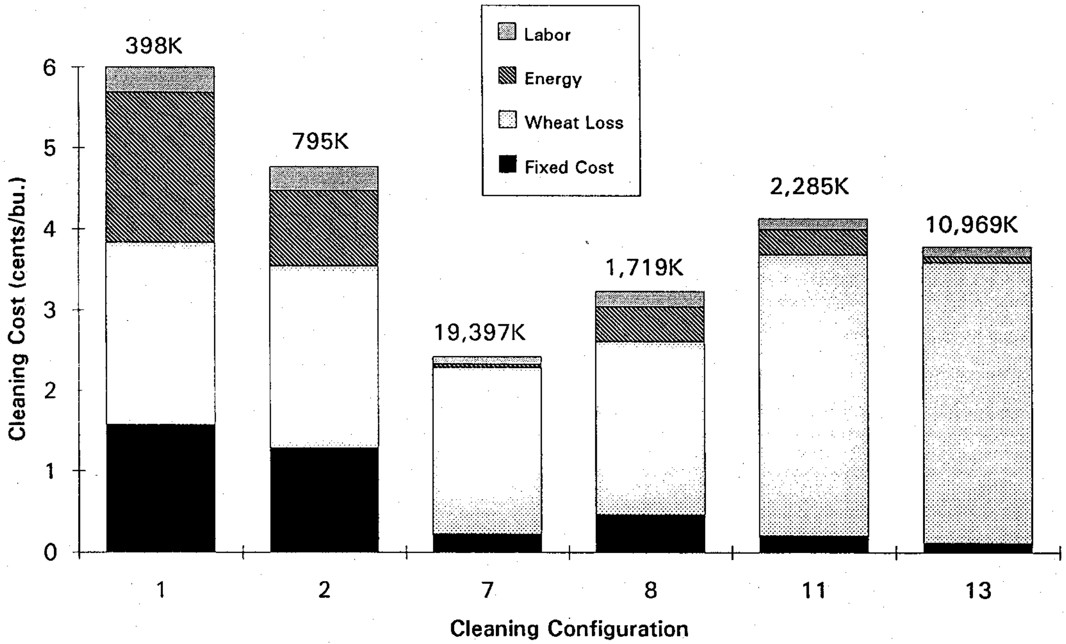

Figure 1. Components of cleaning cost for six representative cleaning configurations

Note: The initial parameter values shown in table 2 are used here. Numbers above each bar indicate thousands of bushels cleaned per year.

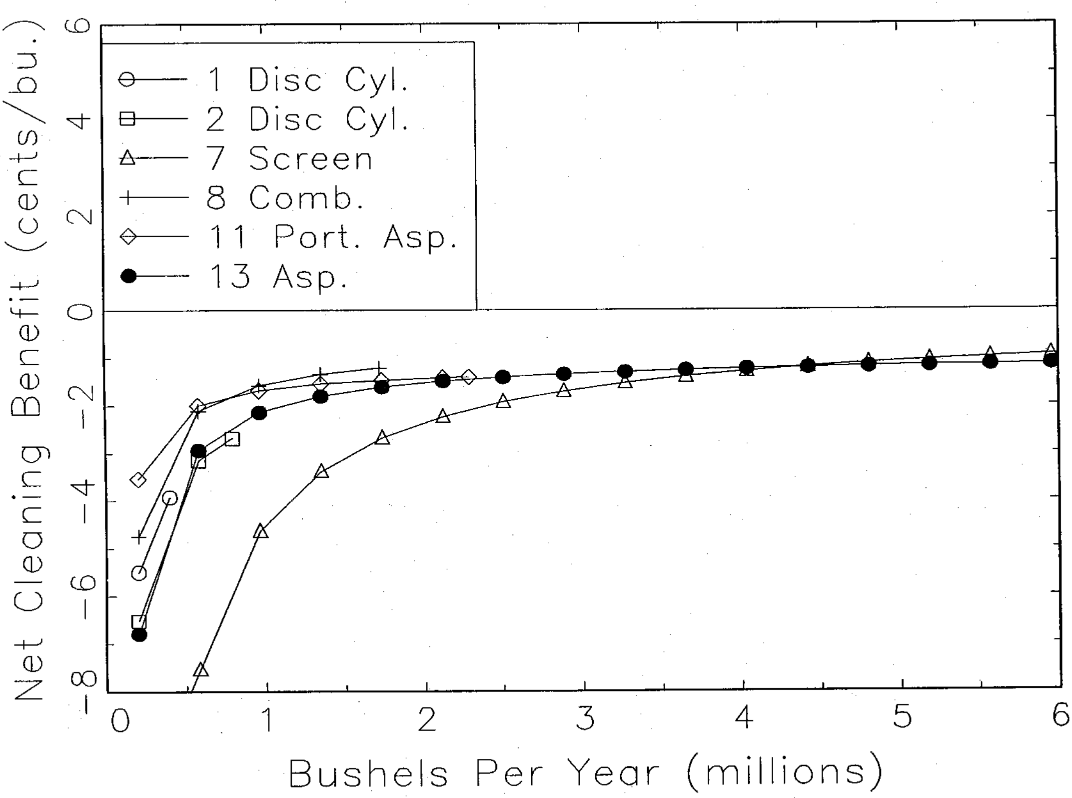

Figure 2. Net benefit of cleaning (¢/bu.) vs. bushels cleaned per year for six representative cleaning configurations

Note: The initial parameter values shown in table 2 are used here.

tance in these cost estimates suggests a need for additional, more comprehensive research on amount of wheat and nonwheat material removed when cleaning down to various levels of dockage.

Average fixed cost is eight times higher for machine #1 than for machine #7. However, the actual (not rated) throughput at which those costs are calculated is 398 bushels per hour for machine #1, and 19,397 bushels per hour for machine #7. At those rates, machine #1 would clean 398,000 bushels in 1,000 hours, while machine #7 would clean 19,397,000 bushels, more wheat than many states produce in a year. These results are sensitive to capacity utilization; operating at less than capacity greatly increases per bushel costs.

The importance of economies of size and capacity utilization on profitability of cleaning is illustrated in figure 2. Although the largest machines (e.g., configuration #7) have the highest net benefit when operated at capacity, their profitability drops rapidly when bushels cleaned per year is reduced. In contrast, the smaller machines (e.g., configuration #2) have lower net benefit when compared at full capacity, but have higher net benefit than other configurations when bushels cleaned per year is low.

National Estimates

Adjusting for differences in operating conditions among states and marketing levels illustrates the importance of operating environment on profitability of cleaning wheat. A summary of NGFA survey information on amount of all classes of wheat handled by country and subterminal elevators in each state can be found in table 4. Responding

Table 4. Average Throughput of All Classes of Wheat at Country and Subterminal Elevators, Based on NGFA Survey

State	Survey Respondents	Average Country Elevator Throughput (bu./year)	Average Subterminal Elevator Throughput (bu./year)
AL	2	201,000	—
AZ	0	—	—
AR	3	371,667	—
CA	1	1,000,000	—
CO	8	2,808,333	2,796,150
FL	0	—	—
ID	5	3,090,000	—
IL	65	129,108	—
IN	31	154,290	3,500,000
IA	7	19,718	100,000
KS	85	621,270	8,995,990
KY	3	176,667	—
LA	2	469,797	—
MD	1	75,000	—
MI	14	314,308	150,000
MN	57	549,176	61,230
MS	8	160,000	—
MO	22	130,837	3,103,433
MT	8	416,875	—
NE	62	351,566	2,802,111
NM	3	573,333	—
NY	3	85,333	—
NC	2	162,500	—
ND	37	1,069,670	—
OH	40	297,775	3,637,500
OK	20	766,174	54,122,000
OR	4	300,000	—
PA	0	—	—
SC	3	290,000	—
SD	39	727,275	—
TN	3	270,000	—
TX	35	491,730	19,249,032
UT	0	—	—
VA	1	400,000	—
WA	39	1,073,489	—
WV	0	—	—
WI	16	92,688	—
WY	0	—	—

Note: Dashes (—) indicate that no elevators responded to the survey.

elevators identified themselves as either country or subterminal elevators and reported the average amount of wheat handled by the elevator in recent years.[14]

Tables 5 through 8 contain results of optimizing equation (1) under a policy of maximum dockage levels for U.S. export wheat. The optimal cleaning location and configuration for each state are shown in table 5, along with the amount of wheat cleaned per cleaning configuration, amount of the state's wheat that is cleaned, and the number of cleaning installations required to clean that wheat. Amount of wheat cleaned per cleaner depends on the cleaning configuration chosen as well as on amount of wheat handled by elevators in the state. In the optimal configuration, wheat from 10 states is cleaned at port installations.

The total amount of wheat received by ports from all states, the amount of wheat cleaned at each of the four port areas from the 10 states cleaning at port, and the type and number of cleaning configurations installed at each port are detailed in table 6. Note that the amount of wheat received by ports (928,110,000 bu.) is slightly greater than the

Table 5. Optimal Cleaning Configuration for Each State

State	Cleaning Location	Optimal Config.	Bushels per Cleaner	Total Bushels Cleaned	No. of Clean-ers Re-quired
AL	subterminal	6	2,910,000	4,170,000	2
AZ	subterminal	6	5,030,000	5,500,000	2
AR	subterminal	6	6,350,000	20,500,000	4
CA	port	port	9,630,000	4,500,000	—
CO	country	11	536,000	26,600,000	50
FL	subterminal	8	1,230,000	592,000	1
ID	country	6	2,340,000	53,100,000	23
IL	subterminal	10	6,060,000	24,900,000	5
IN	port	port	9,630,000	6,580,000	—
IA	port	port	9,630,000	3,710,000	—
KS	subterminal	9	2,870,000	138,000,000	49
KY	subterminal	9	3,140,000	3,680,000	2
LA	subterminal	6	6,350,000	7,830,000	2
MD	subterminal	6	3,130,000	2,270,000	1
MI	port	port	9,630,000	15,500,000	—
MN	port	port	9,630,000	69,300,000	—
MS	subterminal	6	3,580,000	3,720,000	2
MO	subterminal	6	1,960,000	31,400,000	17
MT	subterminal	6	6,350,000	38,500,000	7
NE	port	port	9,630,000	19,300,000	—
NM	subterminal	6	1,800,000	4,130,000	3
NY	subterminal	6	2,740,000	2,570,000	1
NC	port	port	9,630,000	773,000	—
ND	subterminal	6	1,750,000	63,300,000	37
OH	subterminal	8	1,130,000	18,300,000	17
OK	subterminal	10	7,220,000	83,100,000	12
OR	subterminal	4	5,150,000	32,200,000	7
PA	subterminal	6	1,160,000	1,300,000	2
SC	subterminal	6	1,470,000	2,050,000	2
SD	port	port	9,630,000	8,020,000	—
TN	subterminal	10	7,220,000	8,910,000	2
TX	subterminal	10	7,220,000	99,200,000	14
UT	port	port	9,630,000	431,000	—
VA	subterminal	6	6,350,000	11,500,000	2
WA	subterminal	10	7,220,000	107,000,000	15
WV	subterminal	6	6,350,000	186,000	1
WI	port	port	9,630,000	415,000	—
WY	subterminal	6	1,890,000	1,160,000	1
Total				924,000,000	283

Table 6. Optimal Cleaning Configurations at Export Ports

Export Port	Amount Cleaned by Ports (bu.)	Amount Received by Ports (bu.)	No. of Clean-ers	Opti-mal Config.
Great Lakes	25,640,000	73,060,000	3	10
Atlantic	14,480,000	48,350,000	2	10
Gulf	71,730,000	496,700,000	8	10
Pacific	1,673,000	310,000,000	2	10
Total	113,523,000	928,110,000	15	

Table 7. Costs of Cleaning Export Winter Wheat (¢/bu.)

State	Cleaning Location	Optimal Config.	Fixed Cost	Wheat Loss	Labor Cost	Energy Cost	Total Cost
AL	subterminal	6	.4	2.2	.2	.1	2.9
AZ	subterminal	6	.2	2.5	.2	.1	3.1
AR	subterminal	6	.2	2.2	.1	.1	2.7
CA	port	port	.4	2.7	.3	.1	3.4
CO	country	11	.9	3.5	.3	.1	4.8
FL	subterminal	8	.6	2.3	.4	.2	3.5
ID	country	6	.5	2.3	.2	.1	3.1
IL	subterminal	10	.3	2.3	.2	.2	2.9
IN	port	port	.2	2.6	.2	.2	3.2
IA	port	port	.2	2.7	.2	.2	3.3
KS	subterminal	9	.4	2.4	.3	.2	3.3
KY	subterminal	9	.4	2.3	.3	.2	3.1
LA	subterminal	6	.2	2.3	.2	.1	2.8
MD	subterminal	6	.4	2.1	.2	.1	2.8
MI	port	port	.2	2.4	.3	.2	3.1
MN	port	port	.2	2.7	.2	.2	3.3
MS	subterminal	6	.3	2.4	.1	.1	3.0
MO	subterminal	6	.6	2.2	.2	.1	3.1
MT	subterminal	6	.2	2.5	.2	.1	3.0
NE	port	port	.2	2.7	.2	.2	3.3
NM	subterminal	6	.7	2.4	.2	.1	3.3
NY	subterminal	6	.4	2.1	.2	.1	2.8
NC	port	port	.2	2.3	.2	.2	2.9
ND	subterminal	6	.7	2.3	.1	.1	3.2
OH	subterminal	8	.7	2.3	.5	.2	3.7
OK	subterminal	10	.2	2.4	.2	.2	3.0
OR	subterminal	4	.4	2.5	.2	.1	3.2
PA	subterminal	6	1.1	2.3	.2	.1	3.6
SC	subterminal	6	.8	2.1	.1	.1	3.2
SD	port	port	.2	2.8	.2	.2	3.3
TN	subterminal	10	.2	2.3	.1	.2	2.9
TX	subterminal	10	.2	2.4	.2	.2	3.0
UT	port	port	.2	2.8	.2	.2	3.4
VA	subterminal	6	.2	2.1	.2	.1	2.6
WA	subterminal	10	.2	2.6	.2	.2	3.2
WV	subterminal	6	.2	2.2	.2	.1	2.7
WI	port	port	.2	2.5	.2	.2	3.1
WY	subterminal	6	.6	2.3	.2	.1	3.2
Weighted U.S. Average			.4	2.4	.2	.2	3.2

total amount of wheat cleaned (924,000,000 bu., from table 5), since not all wheat received by port elevators is actually exported from the U.S.; some wheat is "exported" domestically.

The average cost of cleaning wheat from each state using the optimal cleaning configuration is shown in table 7. Costs of cleaning range from 2.7¢/bu. to 4.8¢/bu., with a national weighted average of 3.2¢/bu. Although the biggest source of variation in cleaning cost among states is differences in fixed cost, the largest cost of cleaning wheat is value of wheat and other material lost in cleaning, averaging 2.4¢/bu. Labor and energy costs are the least important costs for most states.

The average cleaning benefit and net benefit (benefit minus cost) for each state using the optimal cleaning configurations are presented in table 8. Benefits of cleaning range from 1.3¢/bu. to 3.5¢/bu., averaging 2.1¢/bu. Differences in cleaning benefits result primarily from differences in cleaning location. Benefits are highest at country elevators and lowest at port elevators. Cleaning at a port elevator, for example, reduces fixed cost for states with a low volume of wheat to be cleaned, since wheat from several states is

Table 8. Benefits and Net Benefit of Cleaning Export Winter Wheat (¢/bu.)

State	Cleaning Location	Optimal Config.	Cleanings Value	Transport Savings	Fumigation/ Aeration/ Storage Savings	Total Benefit	Net Benefit
AL	subterminal	6	1.3	.7	.2	2.2	−.8
AZ	subterminal	6	1.3	.7	.2	2.2	−.9
AR	subterminal	6	1.3	.7	.2	2.2	−.5
CA	port	port	.7	.7	.0	1.3	−2.0
CO	country	11	1.9	1.3	.4	3.5	−1.3
FL	subterminal	8	1.3	.7	.2	2.2	−1.3
ID	country	6	1.3	.8	.4	2.5	−.6
IL	subterminal	10	1.3	.7	.2	2.2	−.7
IN	port	port	.7	.7	.0	1.3	−1.9
IA	port	port	.7	.7	.0	1.3	−1.9
KS	subterminal	9	1.3	.7	.2	2.2	−1.1
KY	subterminal	4	1.3	.7	.2	2.2	−.9
LA	subterminal	6	1.3	.7	.2	2.2	−.7
MD	subterminal	6	1.3	.7	.2	2.2	−.6
MI	port	port	.7	.7	.0	1.3	−1.8
MN	port	port	.7	.7	.0	1.3	−1.9
MS	subterminal	6	1.3	.7	.2	2.2	−.8
MO	subterminal	6	1.3	.7	.2	2.2	−.9
MT	subterminal	6	1.3	.7	.2	2.2	−.8
NE	port	11	1.9	.9	.2	1.3	−2.0
NM	subterminal	6	1.3	.7	.2	2.2	−1.1
NY	subterminal	6	1.3	.7	.2	2.2	−.7
NC	port	port	.7	.7	.0	1.3	−1.8
ND	subterminal	6	1.3	.7	.2	2.2	−1.1
OH	subterminal	8	1.3	.7	.0	2.2	−1.5
OK	subterminal	10	1.3	.7	.2	2.2	−.8
OR	subterminal	4	1.3	.7	.2	2.2	−1.0
PA	subterminal	6	1.3	.7	.2	2.2	−1.5
SC	subterminal	6	1.3	.7	.2	2.2	−1.0
SD	port	port	.7	.7	.0	1.3	−1.9
TN	subterminal	4	1.3	.7	.2	2.2	−.7
TX	subterminal	4	1.3	.7	.2	2.2	−.8
UT	port	port	.7	.7	.0	1.3	−2.0
VA	subterminal	6	1.3	.7	.2	2.2	−.4
WA	subterminal	4	1.3	.7	.2	2.2	−1.0
WV	subterminal	6	1.3	.7	.2	2.2	−.5
WI	port	port	.7	.7	.0	1.3	−1.9
WY	subterminal	6	1.3	.7	.2	2.2	−1.0
Weighted U.S. Average			1.3	.7	.2	2.1	−1.0

combined to take advantage of economies of size. However, it also reduces value of cleanings as well as transportation and storage and aeration savings.

Requiring winter wheat to be mechanically cleaned prior to export would necessitate an initial investment in cleaning capacity of about $28 million.[15] The net cost to the industry of cleaning wheat for enhanced reputation, market share, enhanced worker safety, and reduced pesticide use would average about 1¢/bu. for years with exports and grain flows similar to those of 1985, or about $9.3 million per year.

Implications

Economies of size are present in wheat cleaning. However, even if all size economies are achieved, the reduced transportation costs, insect control costs, and feed value of cleanings are insufficient to offset costs of cleaning for typical elevator conditions. These results assume that cleaning machines are set correctly; deviations from this would increase costs of cleaning.

Some competitors, such as Canada, receive a premium relative to U.S. wheat. Further research is needed to determine how much, if any, of this difference is due to lower dockage, and whether cleaner U.S. wheat would receive a premium. Our results indicate that under a scenario where all U.S. export wheat is cleaned, the premium needed to reach breakeven ranges from .4¢/bu. to 2¢/bu., depending on operating conditions, with a national weighted average of 1¢/bu.

The results suggest important implications for regional impacts of a mandatory cleaning program. If mandatory cleaning is implemented in order to accomplish strategic objectives or to achieve public good benefits, regions facing conditions such as those modeled here for CA, IN, IA, MI, MN, NE, SD, UT, and WI will bear more of the cost of cleaning than regions facing conditions such as those modeled for AR, ID, MD, VA, and WV.

Although many factors contribute to differences in operating environments and the optimal choice of cleaning configuration and location, one of the more important is differences in amount of wheat handled. Another is type of dockage problems prevalent in a state, which restricts the type of cleaner that may be effectively used. Flexibility in choosing cleaning configurations and their locations to correspond with operating conditions alleviates some of the effects of these differences. For example, although benefits of cleaning are likely to be highest at inland locations, fixed costs are likely to be higher there also. Thus, a policy attempting to maximize cleaning benefits by mandating cleaning at inland locations is likely to be more costly than a policy allowing flexibility in cleaning location.

Some elevators may face different opportunities than those represented here. For example, elevators with better than average markets for cleanings (e.g., a pelletizing facility for cattle feed), or those which are able to negotiate premiums for clean wheat, may find it profitable to clean wheat to the levels of dockage described here.

This analysis has not addressed the question of profitability of cleaning wheat with higher than normal levels of dockage to normal levels. Cleaning in such cases likely will be profitable because of the discounts often charged for wheat with high levels of dockage.

This economic-engineering analysis provides estimates of cleaning costs and benefits consistent with constraints of current technology and market patterns. Although economic parameters vary across locations and over time, the underlying engineering specifications provide a stable framework for analysis under alternative market patterns. Analysis under 1985 patterns suggests that the net cost to the grain industry of a mandatory cleaning policy in order to achieve strategic and public good benefits would average 1¢/bu., or $9.3 million yearly.

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Notes

[1] Presumably, there are several alternative mechanisms for implementing these requirements, including taxes and subsidies as well as fiat. This analysis focuses on the economic costs and benefits of meeting those requirements by mechanical cleaning, abstracting from the actual implementation mechanism.

[2] The official definition of dockage is "[a]ll matter other than wheat that can be removed from the original sample by use of an approved device [Carter Dockage Tester] according to procedures prescribed in FGIS instructions. Also [included are] underdeveloped, shriveled, and small pieces of wheat kernels removed in properly separating the material other than wheat and that cannot be recovered by properly rescreening or recleaning" (FGIS, p. 13.11). Foreign material is "[a]ll matter other than the wheat that remains in the sample after the removal of dockage and shrunken and broken kernels" (FGIS, p. 13.31). "This may include such things as weed seeds similar in size and density to wheat and dust. It is probable that foreign material will remain in a representative sample of wheat even when most of the dockage is removed by the Carter Dockage Tester" (Fridirici et al., p. 2).

[3] $PVIFA_{ni}$ denotes present value interest factor for an annuity of n years at i percent interest. $PVIFA_{ni} = [1 - (1/(1 + i))^n]/i$, where n is the usable life of the machine and i is the interest rate on the loan.

[4] FGIS has proposed for public comment new grades which include dockage as a grade factor. This analysis does not explicitly consider those proposals. If new grade factors are introduced, discount/premium schedules for current grades will be inappropriate for valuing the new grades.

[5] This calculation differs slightly depending on mode of transportation. See Adam and Anderson for details.

[6] These savings also could be attained by applying Reldan grain protectant or by using grain spreaders, rather than by cleaning.

[7] The estimates assume that cleaning machines are configured and set correctly; costs of cleaning are higher for less-than-ideal operating conditions.

[8] The amount by which removal of fm and s&b increase the value of remaining wheat is accounted for in calculation of grade changes.

[9] The savings of ocean freight are overstated to the extent that demand for U.S. exports is less than perfectly elastic.

[10] To the extent that wheat moves directly from country elevator to port, the merchandising margin may be overstated, transportation cost may be understated, and transportation savings from cleaning wheat may be understated.

[11] Reducing annual throughput increases average variable costs because some variable costs, such as labor and energy, vary more with number of hours operated than with number of bushels cleaned.

[12] It is assumed that all cleaners are installed new. The net benefit of cleaning is a long-run calculation which assumes that all costs of cleaning must be covered. Although the NGFA survey identified existing cleaning capacity, it is less than 5% of that required to clean all export grain. Also, some of the existing capacity is likely inappropriate for the intensity of cleaning modeled here.

[13] The amounts of fm and s&b removed in cleaning were insufficient to increase the grade of typical winter wheat (Adam and Anderson).

[14] Only elevators which reported a nonzero amount are included in survey responses.

[15] This assumes that 281 cleaning configurations are installed at country and subterminal elevators at an average purchase and installation cost of $91,000, and 15 cleaning configurations are installed at port elevators at an average purchase and installation cost of $135,000.

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